BULK GaAs PHOTONIC DEVICES WITH TWO OPPOSITE GRIDDED ELECTRODES

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ABSTRACT

In applications requiring more than one switch, such as the Marx Generator or the Frozen Microwave Generator, three critical properties are large voltage hold-off, good effective quantum efficiency, and fast risetime. In this regard a promising switch design is one in which the electrodes on opposite sides of the switch are gridded and the light is introduced parallel to the applied electric field through the open holes in the electrode. Gridded devices, with a 5mm gap thickness, have demonstrated over 35 kV voltage capability as well as high efficiency, requiring less than 0.5 mJ to turn on. Incorporating these optically activated switches (OAS) into a Frozen Microwave Generator [1] has resulted in peak to peak megawatt output power levels, obtained at UHF.

INTRODUCTION

In an effort to achieve an OAS having high voltage hold-off capability and high quantum efficiency, an extensive investigation of the optically activated gridded bulk GaAs device was conducted at ET&D Laboratory. It was found previously that an openness ratio of 50 % gave maximum switching efficiency [2]. To activate the OAS it is necessary to deliver sufficient optical energy at the proper wavelength. The profile of the photon generated initial carrier density may be estimated following certain simplifying assumptions. Assuming the quantum efficiency is approximately unity and carrier generation is linearly dependent on the laser absorption, the generated carrier density N(x) in a device of thickness L may be expressed as:

$$N(x) = N(o)Exp(-Kx) + \text{reflection terms}$$

which is characteristic of the single sided device, or by:

$$N(x) = N(o)Exp(-Kx) + N(L)ExpK(x-L) + \text{reflection terms}$$

which is characteristic of the double sided device where N(o) and N(L) are the first pass densities near the electrode faces and K is the absorption coefficient. The calculated profiles for two different device lengths (L =5 mm and 7 mm) are shown in Figure 1. The reflection coefficient was assumed to be 0.3. The more uniform density distributions of the symmetric device are evident. Since the measured absorption length of the Nd:YAG laser (1.06 microns wavelength) is 4.32 mm, a one sided illumination of a thick switch (≥5 mm) has potential problems associated with the density profile. As shown in Figure 1, the light creates a highly asymmetric density distribution for the single sided illumination which enhances field intensity at the other side, which in turn may induce a destructive breakdown. In addition such carrier asymmetries may result in slower risetime, reflecting the drift time of the peak carrier density near the side being illuminated.

In general, the voltage capability of the OAS is proportional to the gap distance between two electrodes. To increase the voltage capability, it is necessary to make larger gap devices. The use of two opposite gridded electrodes enables the OAS to have a larger effective gap distance, thus increasing the voltage capability while maintaining fast risetime. This design induces a symmetrical carrier density distribution, which results in OAS devices which are not only fast, but also able to withhold higher voltages. In this paper, we report on significant progress made in design, fabrication, and testing of optical switches with opposite gridded electrodes.

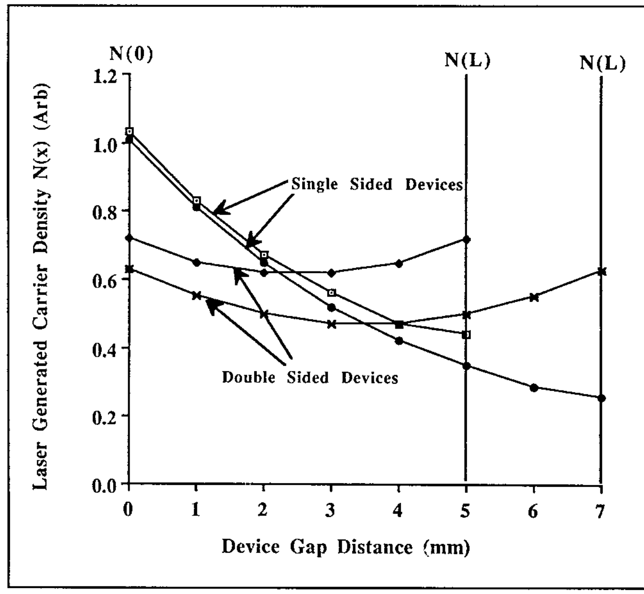

Figure 1. Comparison of Calculated Photon Generated Carrier Densities for Single and Double Sided Gridded Electrode Devices. Device Lengths of 5mm and 7mm are Shown.

SWITCH DESIGN AND FABRICATION

Switch Design

In the gridded electrode OAS the laser light is introduced parallel to the applied electric field. A gridded electrode with a small openness ratio blocks the laser light penetration but gives a uniform electric field strength across the gap distance. Uniform high electric fields provide better conduction. On the other hand, although the higher laser energy coupling into the semiconductors with larger openness ratios generates more electron-hole pairs, such devices have nonuniform electric fields. Therefore, the uniform high electric fields and the laser energy coupling efficiency through the holes in the gridded electrode have an inverse relationship. A previous investigation [2] showed that maximum switching efficiencies occurred in the 40 % to 60 % range of openness ratios for a single sided device. Based on these experimental results, a new double sided switch, with a 50% openness ratio, was designed with the CAD system at ET&D Laboratory. The computer generated mask is shown in Figure 2.

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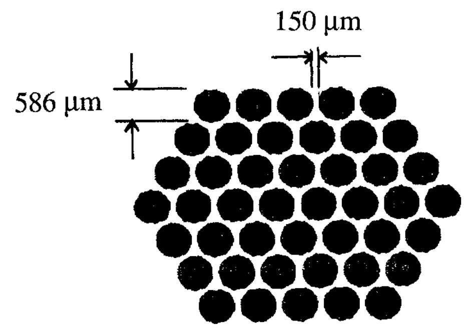

Figure 2. CAD Generated Mask Pattern.

Switch Fabrication

Switches were fabricated by Class 100 clean room processing of chem-mechanically polished semi-insulating (100) GaAs wafers from M/A-COM. Substrate resistivity was 4E7 ohm-cm with dimensions of 5.1 cm diameter and 0.5 cm thickness. Two devices, each 2.2 cm on edge, were obtained from each wafer by a photoresist lift-over process. Orthogonal saw cuts served as a reference for the alignment of the front and back electrode patterns which had a 1.0 cm outer diameter. The electrode apertures, 586 microns in diameter and separated by 150 microns, were located within an area with a 0.6 cm diameter.

The wafers were ultrasonically cleaned with organic solvents and deionized wafer, and patterned with a Kassper contact aligner using Hunts 1350J photoresist. After the photoresist pattern was made on both sides, each face of the wafer was metallized with 50 A nickel, 300 A germanium, 600 A gold, 1000 A silver, and 1000 A gold. Photoresist and excess metal were lifted-off by ultrasonic immersion in acetone, leaving the gridded aperture electrode patterns.

EXPERIMENTAL RESULTS AND DISCUSSION

In most bulk OAS devices tested at high biasing voltage, the breakdown occurs at much lower voltages, compared to the theoretical bulk material breakdown voltage. This lower breakdown is often either high field induced surface flash-over or spark initiated punch-thru. To suppress premature surface flash-over the OAS is immersed into high dielectric transformer oil. Surface flash-over also is inhibited by the effectively long surface path between electrodes, a characteristic which is allowed by the nature of the gridded design itself. To prevent a destructive punch-thru breakdown, a thin indium coating is added on top of the metalization layer. This thin indium layer makes a good contact between the metalization layer and the outside contact.

The experimental set-up used to test the opposite gridded switches is shown schematically in Figure 3. Laser light was conveyed from the laser to the OAS via fiber optic bundles. From a bundle of 14 fibers (core cladding diameter = 1000 micron) sub-bundles consisting of 4 fibers were made and coupled to the electrodes. Since the Q-switched Nd:YAG laser produces an output energy of 1 joule per pulse with 10 ns pulsewidth, combinations of prisms and neutral density filters were used to attenuate and control the laser light intensity. To compare the differences between one side illumination and two side illumination, the total amounts of laser energy coupled into each device were designed to be approximately the same. In particular, special efforts were devoted to the equal division of the light from the fibers in the case of the two sided device.

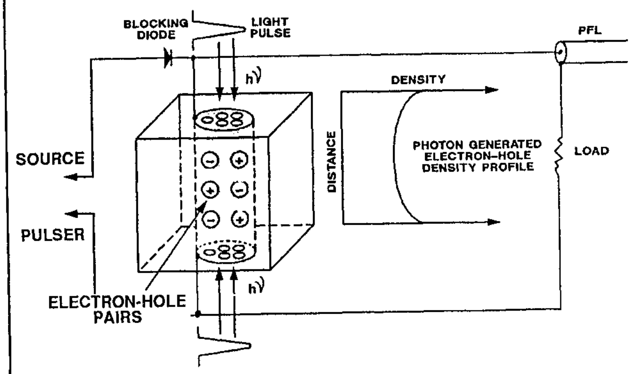

Figure 3. Conceptual Diagram of Optically Activated GaAs Switch with Opposite Gridded Electrodes. The Dual Grid Results in More Uniform Carrier Densities for Thicker Devices.

In addition to the electric field induced breakdown, another breakdown mechanism is thermally induced breakdown. This is the bulk material breakdown associated with high biasing voltage over long periods of time. Instead of high voltage DC biasing, pulse charging was utilized. The pulse forming cable was charged with a pulser consisting of an SCR in combination with a step-up transformer. The voltage waveform of the charging pulse across the OAS is shown in Figure 4.

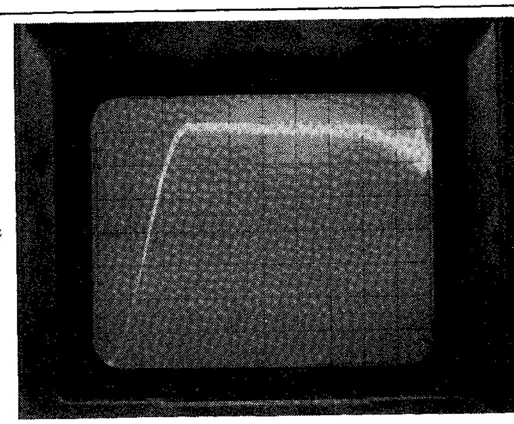

Figure 4. Charge Voltage Waveform

To determine the threshold laser energy and to compare one sided illumination with two sided illumination, several measurements were conducted at various laser energy and biasing voltage levels. The laser energy was varied from 0.025 mJ to 5 mJ and biasing voltages were varied from 2 kV to 12 kV. Figure 5 (a) and 5 (b) show the current waveform obtained in a 5 mm gap OAS charged to 8 kV and illuminated by 0.5 mJ laser energy. It was found that beyond saturation energy, approximately 0.25 mJ - 0.5 mJ, the current waveform is independent of the amount of input laser energy. Also, the light energy needed for lock-on [2] was extremely small (< .05 mJ). The observed risetimes in Figure 5 (a) and 5 (b) show a significant difference in the two cases. The two sided device, in particular, shows a much superior risetime. Among many possible factors which affect risetime, the laser light generated carrier density distribution is considered as possible cause. The observed disparity between the

single and the double sided illumination should be more dramatic in the case of the thicker devices (>5 mm) where the generated carrier slope profile becomes steeper.

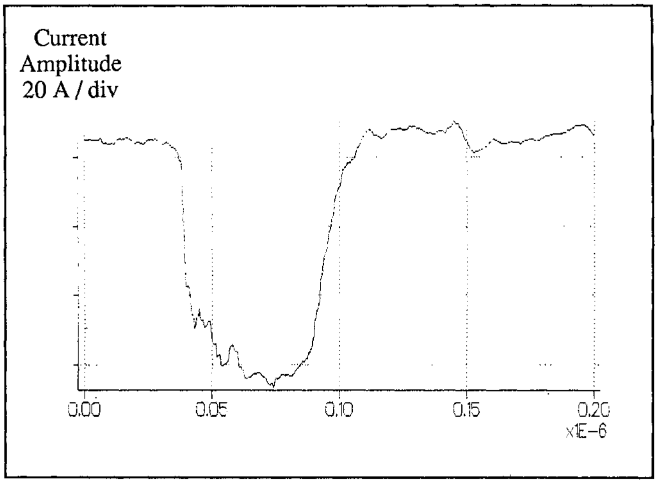

Figure 5a. Current Waveform into 50 Ω load, Resulting from Single Sided Illumination of 5mm Switch with 8 kV Bias Voltage.

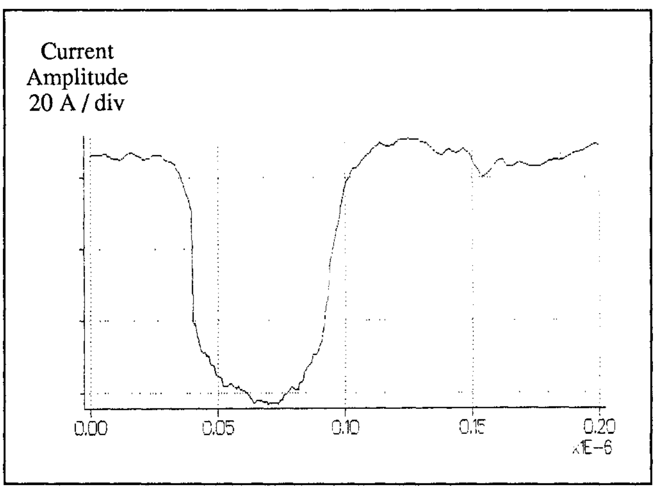

Figure 5b. Current Waveform Under Same Conditions Except for Double Sided Illumination.

The feasibility of the gridded OAS was demonstrated in a particular application, namely the generation of megawatt peak RF power using the Frozen Microwave Generator [1]. Figure 6 shows the obtained RF output waveform from a three stage Frozen Microwave Generator. The burst RF output was produced with a pulse bias of 14 kV. The capability of the RF output power is directly related to the OAS voltage capability, while the RF frequency is determined by the fast risetime capability of OAS. Both characteristics are critical requirements for multiple optically activated device operation.

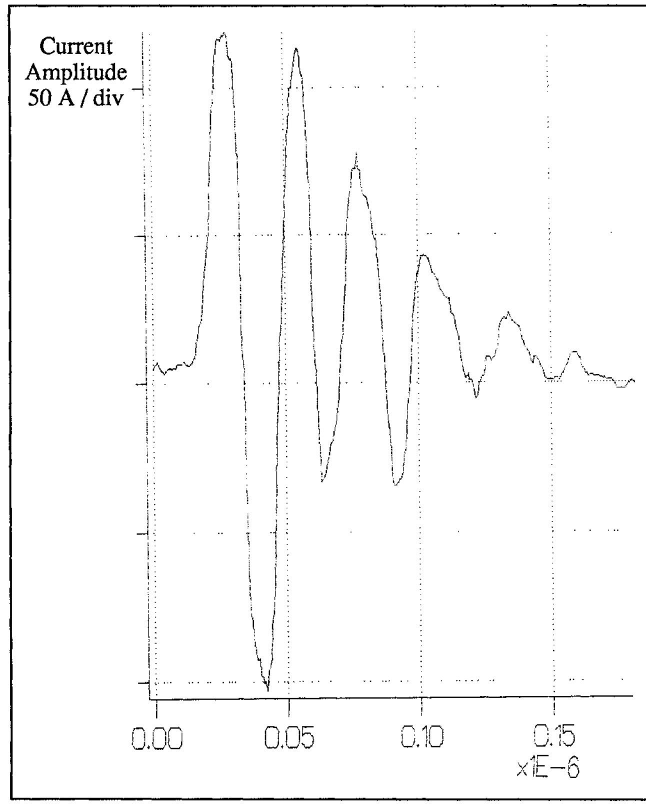

Figure 6. Megawatt Peak-To-Peak RF Output Obtained with 5mm Gridded Switches in a 3 Stage Frozen Wave Generator.

CONCLUSIONS

Photoconductive GaAs devices utilizing two opposite gridded electrodes have demonstrated high switching efficiency, high voltage capability, and improved risetime. With less than 0.5 mJ laser energy an OAS having 0.3 cm active area, with an 0.5 cm gap, demonstrated switching power capability of 12 MW. The feasibility of multi-megawatt output power RF generation was demonstrated by incorporating gridded optically activated devices into the Frozen Microwave Generator.

REFERENCES

1. A. Kim, M. Weiner, R. Youmans, P. Herczfeld, and A. Rosen, "High Power RF Generation With Optically Activated Bulk GaAs Devices", 1988 IEEE MTT-S International Microwave Symposium Digest, May 1988.

2. A. Kim, M. Weiner, M. Dornath - Mohr, M. Wade, R. Youmans, and R. Zeto, "Photonic Switching And The Lock-on Phenomenon in Single Crystal Semi-insulating GaAs", SPIE Proceeding Vol.993, 1988.